Prompt photon production with POWHEG

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Work done in collaboration with F. König

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References

Recent related publications:

- MK, C. Klein-Bösing, F. König, J.P. Wessels
  How robust is a thermal photon interpretation of the ALICE low-p_T data?
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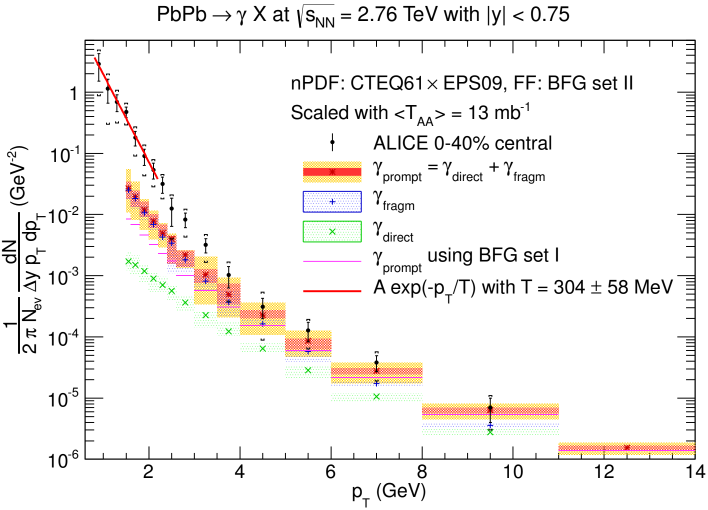
- MK, C. Klein-Bösing, K. Kovarik, G. Kramer, M. Topp, J.P. Wessels
  NLO Monte Carlo predictions for heavy-quark production at the LHC: pp collisions in ALICE
  JHEP 1408 (2014) 109 [arXiv:1405.3083]

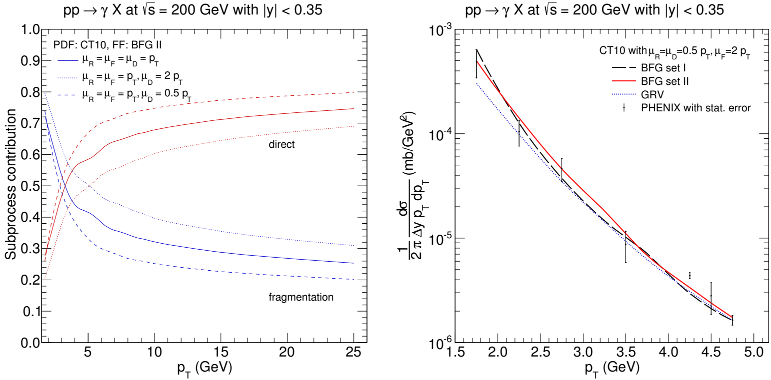
How robust is a thermal photon interpretation ...?

MK., C. Klein-Bösing, F. König, J.P. Wessels, JHEP 1310 (2013) 119



New information on photon fragmentation functions

MK., F. König, Eur. Phys. J. C 74 (2014) 3009



Recalculation of direct processes at NLO

MK, F. König, to be published.

Leading order:

- Tree-level processes: $q\bar{q} \to \gamma g$, $qg \to \gamma q$
- Also with color and spin correlations (needed for POWHEG)
- Traces with FormCalc 8.4, checked against literature and MG5

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Virtual corrections:

- One-loop processes: $q\bar{q} \to \gamma g$, $qg \to \gamma q$
- Tensor reduction w/ Form, scalar functions w/ LoopTools 2.13
- Renormalization in $\overline{\mathrm{MS}}$, checked against MG5_aMC@NLO

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Real corrections:

- Tree-level processes: $q\bar{q} \to \gamma gg(q\bar{q})$, $qg \to \gamma qg$, $gg \to \gamma q\bar{q}$
- Traces with FormCalc 8.4, checked against MG5
- Dipole subtraction, QCD checked against AutoDipole 1.2.3
- Integrated QED dipole reproduces fragmentation function

Reference calculation and choice of input parameters

NLO calculation: [P. Aurenche et al., Phys. Rev. D 73 (2006) 094007]

- JETPHOX
- Direct and fragmentation contributions

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- Variations by relative factors of two, but not four

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Photon fragmentation function: [L. Bourhis et al., Eur. Phys. J. C 2 (1998) 529]

- BFG set II

The POWHEG method

P. Nason et al., JHEP 0411 (2004) 040; 0711 (2007) 070; 1101 (2011) 095

NLO calculations:

- Increase normalization, reduce scale dependence (μ, μ_p, μ_γ)
- Include only one additional parton, no hadronization

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Parton shower Monte Carlos:

- Leading-order normalization, large scale dependence
- Many additional partons, different hadronization models

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NLO+PS with POWHEG:

- Subtract overlap with FKS [Frixione, Kunszt, Signer., Nucl. Phys. B 467 (1996) 399]
- Generate hardest radiation first, only positive weights
- Match to any PS (PYTHIA, HERWIG, ...) with p_T veto

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Required ingredients:

- Color- and spin-correlated squared Born amplitudes
- Finite (UV-renormalized and IR-subtracted) loop amplitudes
- Real emission squared amplitudes

Specific issues for photons

MK, F. König, to be published.

"Fragmentation" contribution: [S. Höche et al., Phys. Rev. D 81 (2010) 034026]

- QED parton shower ($q \to q\gamma$), matched to NLO direct cont.
- Suppressed wrt. to QCD by α/α_s, color factors, multiplicities
- Globally only 2% photons in total QCD+QED event samples
- Reweight QED radiation by $C = 50\,(100)$, check independence

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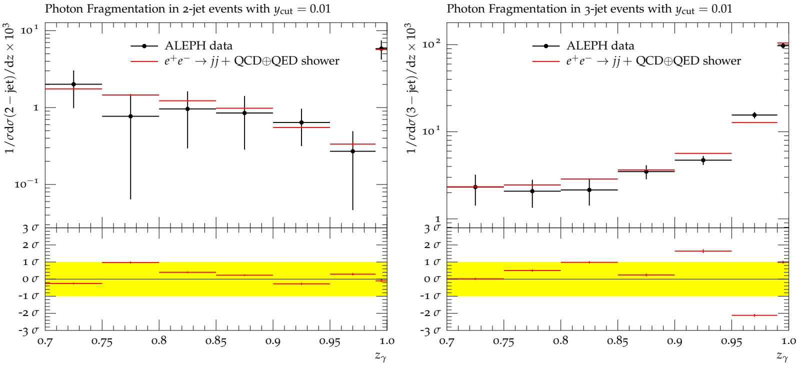
Symmetrization of parton splitting in the final state:

- `doublefsr=1`
- Reduces POWHEG cross section by 10%

Photon fragmentation function in 2- and 3-jet events

S. Höche et al., Phys. Rev. D 81 (2010) 034026 (Fig. 1)



Excellent description of ALEPH data [ALEPH Coll., Z. Phys. C 69 (1996) 365]

Works also for other jet resolution parameters $y_{\text{cut}} \geq \min\left(\frac{E_i}{E_j}, \frac{E_j}{E_i}\right) \cdot \frac{s_{ij}}{s}$

Born suppression factor

P. Nason, C. Oleari, arXiv:1303.3922

Born-level event generation cut:

- $pp \to \gamma + X$ has coll. divergence at LO $\to$ impose $p_T > p_T^{\mathrm{min}}$
- Influences events at low p_T $\to$ region of interest for thermal γ
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Analytic Born suppression factor:

- Multiplies Born cross section
  - POWHEG ($p_{T,\mathrm{peak}} = 10$ GeV, power $i = 3$):

$$f_{\mathrm{sup.}} = \left(\frac{p_T^2}{p_T^2 + p_{T,\mathrm{peak}}^2} \right)^i$$

  - Approximation of $\Theta(p_T - p_T^{\text{min}})$ (e.g. with $p_T^{\mathrm{min}} = 1$ GeV):

$$f_{\mathrm{sup.}} = \frac{1}{\pi} \left[\arctan[(p_T - p_T^{\text{min}}) \cdot 10^4] + \frac{\pi}{2} \right]$$

- Events then reweighted by $1/f_{\mathrm{sup.}}$, checked independence

Experimental conditions

PHENIX Collaboration at RHIC

Center-of-mass energy: $\sqrt{s}_{pp} = 200$ GeV

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Inclusive photons: [Phys. Rev. C 87 (2013) 054907 and D 86 (2012) 072008]

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- $p_T^\gamma \in [1; 5]$ and $[5; 25]$ GeV
- $|\eta^\gamma| < 0.35$

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Isolated photons: [Phys. Rev. D 86 (2012) 072008]

- $E^{\mathrm{had.}}/E^\gamma \leq 0.1$
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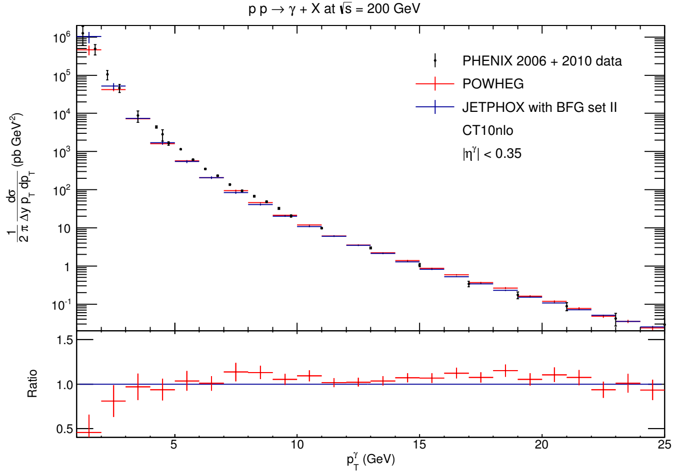
Photons + jets: [Phys. Rev. C 80 (2009) 024908]

- $\mathcal{L}\ (\mathrm{Runs}\ 2005 + 2006) = 3.0 + 10.7\ \mathrm{pb}^{-1}$
- Anti-k_T cluster algorithm with $R = 0.4$

Comparison of NLO and POWHEG with PHENIX data

MK, F. König, to be published.

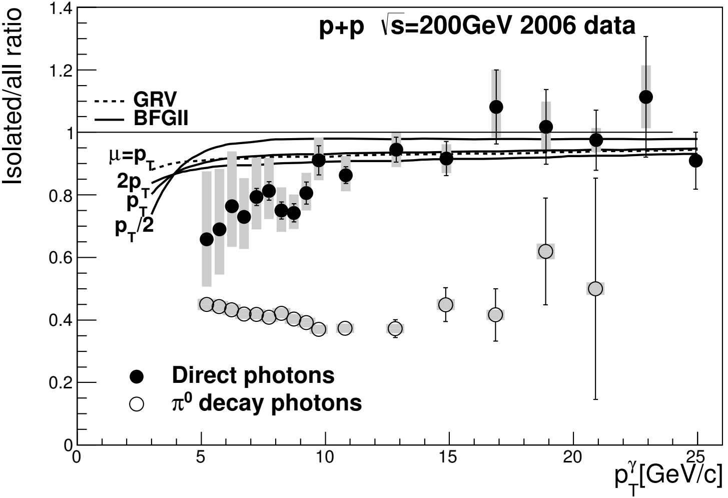


JETPHOX ($\mu = \mu_p = \mu_\gamma = p_T$) too large at low p_T → fragmentation cont.

JETPHOX ($\mu = \mu_p = 0.5\, p_T, \mu_\gamma = 2\, p_T$) better [MK, F. König, EPJC 74 (2014) 3009]

Fraction of isolated photons at NLO

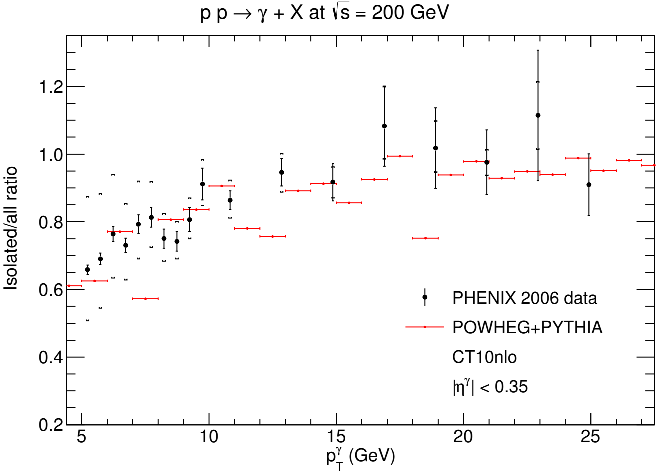
PHENIX Coll., Phys. Rev. D 86 (2012) 072008 (Fig. 13)



NLO too high at small and intermediate p_T for all scale choices

Fraction of isolated photons with POWHEG

MK, F. König, to be published.

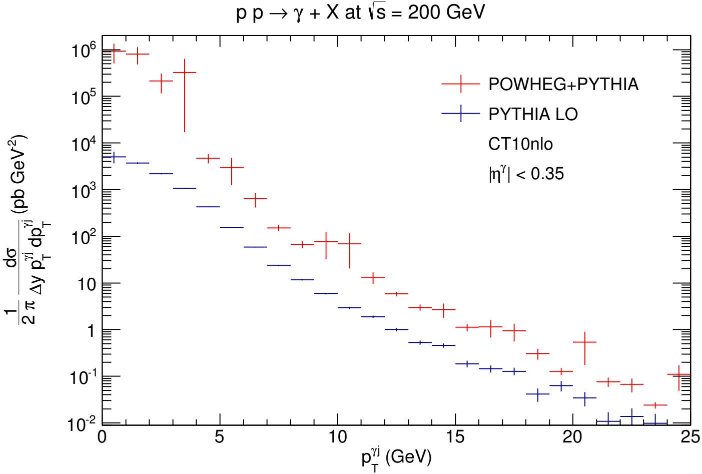


POWHEG gives first correct description

Scale uncertainty cancels completely (no fragmentation cont.)

Transverse momentum balance of photons and jets

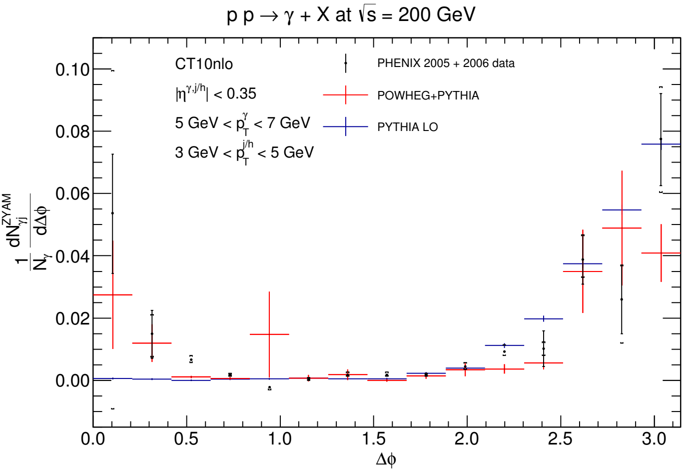
MK, F. König, to be published.



- Individual cuts on $p_T^\gamma > 1$ GeV and $p_T^j > 1$ GeV
- At $p_T^{\gamma j} \to 0$ NLO diverges, PYTHIA/POWHEG have finite turnover
- PYTHIA underestimates absolute cross section in particular at low p_T

Azimuthal correlation of photons and jets

MK, F. König, to be published.

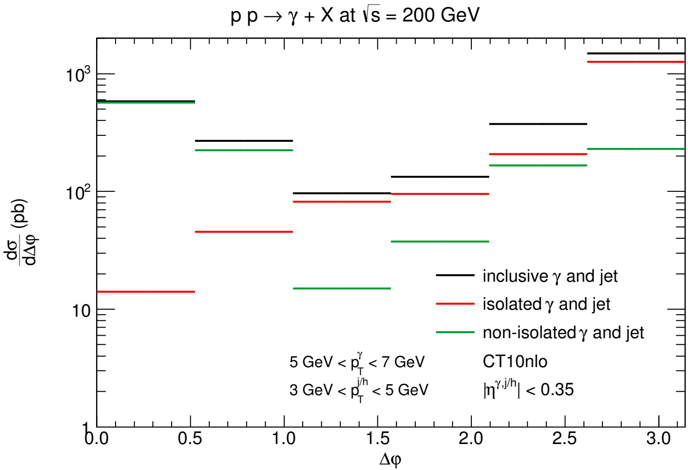


At $\Delta\phi \to \{0, \pi\}$ NLO diverges, PYTHIA/POWHEG have finite turnover

PYTHIA has no “fragmentation” and wrong normalization (not shown)

Contributions of isolated and "fragmentation" photons

MK, F. König, to be published.



"Fragmentation" processes mostly collinear ($\Delta\phi \simeq 0$, but also π)

Conclusion

Motivation:

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- Photon-jet correlations important for jet quenching

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- Experimental conditions: PHENIX at RHIC

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Results:

- Improved agreement with p_T spectrum of inclusive photons
- First correct description of isolated photon fraction
- Reliable prediction for photon-jet p_T-balance
- First correct description of photon-jet azimuthal correlation
- Decomposition into isolated and "fragmentation" photons

Outlook

What remains to be done:

- Application to pA and AA collisions
- Study cold nuclear effects with nPDFs
- Implement medium effects (energy loss, hydrodynamics, ...)